Environmental Water Program Draft Conceptual Proposal for Flow Acquisition on Lower Clear Creek

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1 PROJECT DESCRIPTION

1.1 Statement of Problem and Project Vision

Clear Creek provides a good example of an ecosystem-based approach to restoration in the Central Valley. Since 1996, local, state, and federal partners have augmented the creek's gravel supply, generally using a flow-based strategy, whereby the gravels that are placed on the banks and floodplain are recruited into the channel and distributed by high flow events, rather than being placed directly in the channel. Similarly, there have been efforts to reconstruct 2.2 miles of the channel and floodplain morphology as part of the Lower Clear Creek Floodway Rehabilitation Project (2000–present), and the design of these physical modifications assumes the presence of flows to help the channel and floodplain environments evolve over time in order to maintain the value of aquatic and riparian habitat. Though these physical modifications embody an ecosystem-based approach by relying on natural processes to create and maintain habitats, the current flow regime generally does not include the types of flows necessary for re-establishing the critical ecological processes that were anticipated by previous restoration efforts in Clear Creek. Particularly absent are mid-range floods (e.g., ~4,000–6,000 cfs) that typically support a number of fundamental riverine processes, such as channel bed mobilization and scour, deposition of fines on floodplains, maintenance of pool depth by scour, and the scouring of riparian vegetation from channel surfaces to prevent encroachment and simplification of the channel and aquatic habitat. Therefore, restoration of mid-range floods has both an intrinsic value in re-establishing important ecological functions, and value in ensuring that the value of recent restoration efforts is maximized.

Consequently, an important step in the restoration of Clear Creek is to provide periodic flow releases that will restore the fundamental ecological processes that help to create and maintain aquatic, riparian, and floodplain habitats that can support a variety of fish, avian, and other wildlife species.

Restoring mid-range floods to Clear Creek will help to create and maintain several different types of habitat units that are envisioned for the lower Clear Creek corridor between Whiskeytown Dam and the confluence with the Sacramento River. Such habitats include:

- framework spawning gravels between Whiskeytown Dam and the canyon reach to support spring-run Chinook salmon and steelhead trout spawning, complemented by overhanging riparian vegetation to provide cover for juvenile salmonid rearing;
- deep, coldwater pools to support salmonid holding in the canyon reach, with LWD to provide habitat complexity, cover for juvenile salmonid rearing, and to induce the deposition of pockets of gravel to support spawning by spring-run Chinook salmon and steelhead trout;
- riffles composed of channel bed sediments that are mobilized and scoured periodically to maintain spawning habitat quality primarily for spring-run Chinook salmon spawning between the canyon reach and the Saeltzer Dam gorge, flanked by floodplains supporting a diverse riparian vegetation including nesting and foraging by neotropical migrant bird species, and incorporating complex channel habitats including floodplain ponds and scour channels to support juvenile salmonid rearing and amphibian species;
- riffles composed of channel bed sediments that are mobilized and scoured periodically to maintain spawning habitat quality to support fall-run Chinook salmon spawning between the Saeltzer Dam gorge and the confluence with the Sacramento River, flanked by floodplains supporting a diverse riparian vegetation including nesting and foraging by

neotropical migrant bird species, and incorporating complex channel habitats including floodplain ponds and scour channels to support juvenile salmonid rearing and amphibian species;

Restoring mid-range floods is expected to create the targeted spawning and rearing habitat between Whiskeytown Dam and the canyon reach by recruiting, distributing, and re-working augmented gravels that are placed on the banks and floodplains, and by depositing fine sediments on floodplains to support colonization of riparian vegetation. Such flows are expected to create and maintain the targeted pool and pocket-spawning habitats in the canyon reach by scouring fine sediments from pools to increase and maintain pool depth to support salmonid holding, and by interacting with flow obstacles (e.g., LWD, boulders) to induce localized pockets of gravel deposition. Mid-range floods will help to create and maintain the targeted spawning riffles and broad, forested floodplains pocked with ponds and scour channels between the canyon reach and the confluence with the Sacramento River by periodically mobilizing and scouring channel bed sediments, by preventing riparian vegetation from encroaching the active channel, and by depositing fine sediments on the floodplain.

Restoring mid-range floods to Clear Creek presents several scientific and management challenges. For example, the relative absence of mid-range floods in the current, regulated flow regime have made it challenging to directly observe, and therefore identify, the specific flow thresholds required to recruit and distribute existing and augmented gravels, to mobilize fine sediment and deposit it on floodplains, to initiate channel migration, and to prevent riparian encroachment. Similarly, it is difficult to define the timing, frequency, and duration of flow releases in order to optimize ecological benefits (e.g., releasing flow to coincide with the seed-release period of key riparian vegetation species) and to prevent or reduce conflicts with other ecological objectives (e.g., the release of scouring flows during critical periods of salmonid egg incubation). It is also difficult to design flow releases that will balance ecosystem restoration needs with other important uses of water, such as hydropower generation and the delivery of irrigation water. These uncertainties and management challenges underscore the need for implementing the restoration of mid-range floods as part of an adaptive management program, in which flow releases are designed to test clearly defined hypotheses and complemented by field investigations and monitoring activities to address pressing management issues.

The objectives of the Environmental Water Program (EWP) make Clear Creek a perfect candidate to provide a supply of water to support the on-going, ecosystem-based management approach to restoration. Several planning activities have cited Clear Creek as one of the best opportunities for restoring flows in a manner that will contribute to existing restoration efforts, while simultaneously providing excellent opportunities to improve our understanding of how to optimize the ecological benefits of restored flows and how to balance environmental flow needs with human uses of water. These planning activities include the Pilot Water Acquisition Program (PWAP) Stream Selection Recommendations (CALFED 2002), the CALFED-Ecosystem Restoration Program's Independent Science Board memorandum (Kimmerer et al. 2002) and a previous Environmental Water Program report (Stillwater Sciences 2003).

1.2 Statement of Purpose

The purpose of this draft conceptual proposal is to describe a suite of flow-related experiments and monitoring activities to accompany the possible acquisition of water for environmental application in Clear Creek. This proposal focuses primarily on defining field investigations and monitoring activities associated with the potential restoration of mid-range floods (e.g., 4,000–

6,000 cfs) in Clear Creek. Also described are studies to establish a pre-project baseline that facilitates analyses of the effects of restoring mid-range floods, and to address key questions about the design of, and hypothesis refinements and testing through, restoration of mid-range floods. These field investigations and monitoring activities are designed to build on recent, current, and proposed physical and biological monitoring efforts (e.g., McBain and Trush 2001, GMA 2003, Burnett and Harley 2003, Bair 1999, WSRCD 1996) to build on the scientific foundation already established in Clear Creek, and to optimize the valuable scientific and management-oriented lessons that can be yielded and applied to Clear Creek and other alluvial streams in the Central Valley.

Clear Creek Reach Delineation

The four reaches of lower Clear Creek referred to in this conceptual proposal (Figure 1) were delineated by McBain and Trush (2001), based primarily on geomorphic characteristics (e.g., channel slope and confinement, alluvial vs. bedrock channel, extent of floodplains and riparian vegetation, etc.), and secondarily on land use impacts resulting from dredge mining for gold, aggregate mining, streamflow regulation, and coarse sediment blockage from Whiskeytown Dam and the former Saeltzer Dam. The four reaches are:

(1) The upstream, confined, alluvial reach directly below Whiskeytown Dam (river mile [RM] 17.5 to 15.4),
(2) The canyon reach from Paige-Bar to Clear Creek Bridge (RM 15.4 to 8.4),
(3) The alluvial reach upstream and downstream of the site of the former Saeltzer Dam, comprising:
    (3A) Reach 3A: Clear Creek Bridge to Saeltzer Dam gorge (RM 8.4 to 6.8).
    (3B) Reach 3B: Saeltzer Dam gorge (RM 6.8 to 6.5).
(4) The alluvial reach downstream of Saeltzer Dam gorge (RM 6.5 to 0.0).

This reach delineation is useful to describe the specific geomorphic conditions of each reach, and to provide a context for identifying specific ecological stressors (CALFED 1999), different anadromous salmonid issues, and for developing restoration actions and strategies that target specific features of the different reaches (for instance, between reaches in the upper bedrock gorge and the lower alluvial reach).

1.3 Background to the Environmental Water Program

The Environmental Water Program (EWP) is part of the California Bay-Delta Authority's (CBDA) Ecosystem Restoration Program (ERP). The U.S. Fish and Wildlife Service (USFWS), National Oceanic and Atmospheric Administration (NOAA) Fisheries, and the California Department of Fish and Game (DFG) are designated as the implementing agencies for the Ecosystem Restoration Program (ERP Implementing Agencies) and are working, in coordination with the CBDA, to implement pilot water acquisitions in selected watersheds through the Environmental Water Program (EWP). The goal of the EWP is to acquire water in support of the ERP to enhance instream flows that are biologically and ecologically significant, improve the state of scientific knowledge related to the effects of instream flows, and gain knowledge regarding the institutional and social constraints facing environmental water acquisitions.

The EWP has recognized the value of water and its potential as a source of conflict among competing interests. Consequently, the EWP is guided by a set of principles to ensure that water acquisitions will be:

- made on a willing seller basis;
- developed jointly by local interests and the ERP Implementing Agencies; and
- designed to test hypotheses regarding water management in a manner that
    - facilitates learning through adaptive management,
    - includes appropriate monitoring, and
    - will be peer reviewed by an independent scientific panel prior to approval.

Proposal Development Process
This draft conceptual proposal for water acquisition was developed by a local proposal preparation team with assistance from the EWP Core Team and EWP Lead Science Team. The proposal will be reviewed by an external team of scientists selected by the CBDA to evaluate its scientific merits. It will also be reviewed by representatives from related water acquisition programs to determine potential synergies with other water acquisition efforts or potential conflicts with the water rights of the Central Valley Project (CVP), State Water Project (SWP), or other water users. Revised conceptual proposals for this and other creeks will be forwarded to the ERP/EWP Selection Panel, which will provide recommendations regarding which conceptual proposals are ready for full proposal preparation. Local preparation teams will then draft full proposals that respond to the recommendations made by the reviewers, and expand upon material provided in the conceptual proposal, including: detailed descriptions of the work to be completed, statements of who will be responsible for completing each element of work, projected costs for each element of work, a science and adaptive management plan, a project management plan, and a water acquisition plan.

1.4 Project Setting

Clear Creek is a 238-square mile watershed draining into the northwestern portion of the upper Sacramento River Basin. Clear Creek originates near 6,000 ft elevation in the Trinity Mountains, and flows south between the Trinity River basin to the west and the Sacramento River basin to the east, and into Whiskeytown Reservoir (elevation 1,210 ft) at Oak Bottom, 11 miles west of Redding (Figure 2). This proposal focuses on Lower Clear Creek which extends for approximately 17 miles from Whiskeytown Dam to the confluence with the Sacramento River five miles south of Redding (elevation 440 feet). Downstream of Whiskeytown Dam, Clear Creek flows south before changing direction and flowing east approximately 8.5 miles upstream of the Sacramento River confluence. The unregulated drainage area between Whiskeytown Dam and the confluence with the Sacramento River is 49 mi^2.

Clear Creek flows through two distinct geologic provinces: the Klamath Mountains province (encompassing Reaches 1 and 2) and the Great Valley province (Reaches 3 and 4) (Blake et al. 1999). The Klamath Mountains province is composed primarily of Paleozoic to Mesozoic igneous, metasedimentary, and metamorphic lithologies that are largely resistant to erosion. The Great Valley province is composed of Mesozoic to Recent sedimentary lithologies, which are much less resistant to erosion that the Klamath Mountain rocks. The different erosion properties between the provinces both influence the composition of the Clear Creek alluvium and cause significant differences in channel morphology (McBain and Trush 2001).

Streamflow hydrology in lower Clear Creek is typical of streams draining the west side of the Sacramento Valley. The maximum watershed elevation is approximately 6,000 ft, but a majority of the watershed area is below the 4,000 ft snow line, so high flow hydrology is driven by rainfall and rain-on-snow events, which typically occurred during the winter months. The unimpaired snowmelt hydrograph is small in magnitude; the snowmelt peak is typically less than 1,500 cfs.

Average annual precipitation in the Clear Creek watershed varies from 20 inches near the confluence with the Sacramento River to over 60 inches in the upper watershed (TAT 1999, p. 6). Unimpaired summer/fall baseflows were low because the imperviousness of the Klamath Mountains terrain minimizes shallow and deeper groundwater storage to the point where no significant springs exist to maintain high baseflows (TAT 1999, p. 6). This imperviousness, combined with periodic high intensity rainstorms, results in extremely flashy streamflow response to rainfall events. For current hydrology, see Section 1.6.1.

1.5 Species of Potential Interest

Fish populations of interest in Clear Creek include anadromous salmonids and resident fish species. Anadromous salmonids listed under the federal Endangered Species Act (ESA) include Central Valley spring Chinook (*Oncorhynchus tshawytscha*, ESA-threatened) and Central Valley steelhead (*Oncorhynchus mykiss*, ESA-threatened). Species of interest that are not listed under the ESA include anadromous Central Valley fall and late-fall Chinook (*Oncorhynchus tshawytscha*) and Pacific lamprey (*Lampetra tridentata*), and native resident rainbow trout (*Oncorhynchus mykiss)*, Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis*), hardhead (*Mylopharodon conocephalus*), California roach (*Hesperoleucus symmetricus*), and hitch (*Lavinia exilicauda*), as well as non-native large mouth (*Micropterus salmoides*) and small mouth bass (*Micropterus dolomieu*) and white catfish (*Ameiurus catus*). Anadromous salmonids are of particular interest due to their ESA status and their recreational and commercial importance. Because anadromous salmonids utilize freshwater habitats for spawning and rearing, the construction of Whiskeytown and Saeltzer dams truncated their distributions within the Clear Creek drainage. The timing of spawning for spring, fall, and late fall Chinook salmon and steelhead in lower Clear Creek are summarized in Figure 3.

Riparian vegetation is limited to a narrow band along the channel margins in the confined canyon reaches of Clear Creek between Whiskeytown Dam and Clear Creek Bridge where the alluvial section of the creek begins. Vegetation occurs in bedrock cracks, and along small tributary deltas and lee deposits; arroyo and narrow leaf willows (*Salix lasiolepis* and *S. exigua*) thrive wherever local site conditions can sustain them. However, there are some areas near Paige Bar, close to the Whiskeytown Dam site, where white alder (*Alnus rhombifolia*) and Pacific willow (*S. lucida ssp. lasiandra*) have colonized along the low water channel. Downstream of Clear Creek Bridge where the valley widens, the channel becomes predominately alluvial, and floodplains and terraces allow riparian vegetation to be more extensive. In the alluvial reaches of Clear Creek, riparian vegetation historically existed in patches near abandoned primary channels or high flow scour channels where the water table was closer to the rooting surface (McBain and Trush 2001).

The lower Clear Creek watershed provides habitat for many wildlife species including various mammals, herpetofauna, and avifauna. Based on geographic and vegetative characteristics, the lower Clear Creek watershed is transitional between valley floor, foothill, and montane wildlife habitats (McBain and Trush 2001, p. 12). This transition is reflected by the wildlife species composition of the area, as a mixture of both resident and migratory valley and foothill/montane species occur (McBain and Trush 2001, p. 12).

1.6 Evidence for Problem

The watershed historical disturbance regime provides the basis for understanding the environmental history of river system changes in time and space across the watershed. For most watersheds, this procedure equates to a cause-and-effect analysis of increasing human interventions affecting the natural hydrologic and geomorphic system function, hence the notion of a ‘disturbance regime’. The analysis is valuable in: (1) identifying the underlying causes of problems or issues leading to the need for restoration (e.g., by experimental discharges); (2) documenting historical conditions that assist in determining ecological potential; and (3) setting realistic and appropriate goals for restoration based on knowledge of desired system end states (Kondolf and Larson 1995; Kondolf and Downs 1996). Cause-and-effect analyses of the watershed historical disturbance regime are predicated on a hierarchy of processes as illustrated in Figure 4. Several reports have traced the degradation of aquatic and floodplain habitats in Clear Creek as a function of various human activities over time (McBain and Trush 1999, Williams and Kondolf 1999, CDFG 1971). Several of these reports have also tried to correlate the loss of habitat quantity and quality with the reduction or elimination of critical river processes, such as the elimination of mid-range floods (i.e., bankfull flow events) by Whiskeytown Dam operations (McBain and Trush 2001) and the longer periods between flows capable of mobilizing and scouring gravel, which has permitted fine sediments to infiltrate framework spawning gravels (Williams and Kondolf 1999). In addition to the numerous reports summarizing historical conditions and the loss of habitat, there have been several recent physical and biological monitoring studies that assist in providing the empirical basis for the proposed flow acquisition (Table 1).

Table 1. Recent physical and biological monitoring activities by reach in lower Clear Creek.

	Reach 1	Reach 2	Reach 3	Reach 4
Physical Monitoring				
Mercury (Ashley et al 2002)	X	X	X	X
Trace metals (Moore 2002)	X	X	X	X
Groundwater monitoring (in rehabilitation sites)			X	X
Geomorphology (McBain and Trush 2001)	X	X	X	X
Geomorphology (Stillwater Sciences 2001)			X	X
Geomorphology, hydrology (GMA 2003)				X
Geomorphology (Miller and Vizcaino 2004)				X
Biological Monitoring				
Riparian songbirds (Burnett and Harley 2003)	X	X	X	X
Riparian vegetation (Bair 1999)	X	X	X	X
Spawning habitat (USFWS and CDFG 1956, 1971)	X	X		
Fish (Villa 1984) (not clear if sampled Reach 1)		X	X	X
Fish (CDFG pers. comm. Colleen Harvey, as cited in WSRCD 1996)			X	X
Fish (USFWS pers. comm. Matt Brown)			X	X

1.6.1 Impacts on watershed inputs

The hydrology and channel morphology of Clear Creek have been altered by flow diversion, sediment interception, and sediment removal. The Trinity River Division of the Central Valley Project has significantly altered the hydrology of lower Clear Creek since the completion of Whiskeytown Dam in May 1963. Other impacts to the river and floodplain include a combination of hydraulic mining for gold (beginning in 1848), in-stream gravel mining (1950–1978), floodplain gravel mining (1950–present.), operation of Saeltzer Diversion Dam (1903–2000) and other land uses in tributaries (e.g, road construction, timber harvest).

Changes in streamflow as a result of flow regulation by Whiskeytown Dam have been dramatic, and have had significant impacts to fluvial processes, riparian dynamics, and salmonid populations. McBain and Trush (2001) analyzed the hydrologic record at the USGS Clear Creek at Igo gauge to assess the impact of Whiskeytown Dam on flow in Clear Creek. They found that Whiskeytown Dam has significantly reduced the magnitude and frequency of high flows less than 10,000 cfs (Table 2). Further, average flow magnitude and variance have decreased (Williams and Kondolf 1999, p. 21). Smaller high flow events of short duration (2,000–3,000 cfs) can still occur due to tributary inflows below Whiskeytown Dam and larger flow events (>10,000 cfs) still occur during large storms that exceed the storage capacity of Whiskeytown Reservoir. While the Whiskeytown spillway can provide uncontrolled releases up to 28,000 cfs, the Outlet Works can only release a maximum flow of 1,200 cfs, which is incapable of initiating any significant fluvial processes (USBR 1999, p. 14). Flows greater than 3,000 cfs generally result from glory hole spillway releases. The frequency of moderate, channel-forming flows typical of a bankfull event prior to dam construction (i.e., 4,000–6,000 cfs; approximately 1.5 year recurrence interval) have been severely reduced (McBain and Trush 2001, p. 80) and now has a frequency of 5–6 years, while the 1.5 year flood magnitude has decreased from 5,700 cfs before Whiskeytown Dam was built to 2,200 cfs post-dam construction. The end result is to reduce the frequency of events that cause bedload sediment transport, that deposit fine sediment on floodplains and that scouring riparian vegetation from the channel edge.

Table 2. Daily-average flood series from the USGS Clear Creek at Igo gauge (McBain and Trush 2001).

Recurrence Interval (years)	Pre-Dam (1941–1963)	Post-Dam (1964–2000)	Percent Reduction
1.5	3,690	926	75
2.5	6,185	1,817	71
5	9,048	3,355	63
10	14,300	5,958	58

Additional hydrograph components have also been altered. The small snowmelt hydrograph has been completely eliminated and summer baseflows, typically less than 20 cfs at the Igo gaging station, are now maintained at 150 cfs to provide adequate water temperatures (cooling flows) for steelhead and spring-run chinook salmon downstream of (former) Saeltzer Dam (TAT 1999, p. 8). These increased baseflows have caused substantial changes in the composition and distribution of riparian vegetation species.

Gold and aggregate mining at Reading Bar and aggregate mining in Reaches 3A and 4 drastically altered the channel and floodplain morphology (McBain and Trush 2001, p. 7), and consequently, the sediment transport processes and species composition in lower Clear Creek. Floodplains were geomorphically isolated from the main channel (McBain and Trush 2001, p. 33). In some areas, aggregate mining removed the floodplain surface altogether, creating shallow depressions which have become wetland complexes (McBain and Trush 2001, p. 33). The complexes were typically connected to the low flow channel, where they function as sediment sinks, potential stranding areas for juvenile salmonids and potential habitat for non-native, piscivores fish species. Channel incision has also been documented on lower Clear Creek, which Williams and Kondolf (1999, p. 4, 5) attribute to a combination of reduced sediment supply downstream of Whiskeytown Dam, downcutting through aggradation resulting from hydraulic mining for gold, in-stream and floodplain gravel mining and the reduced base level of the Sacramento River at the Clear Creek confluence.

1.6.2 Habitat changes

Spawning habitat for spring-run Chinook salmon and steelhead historically existed in Reaches 1 and 2 and farther upstream before Whiskeytown Dam was built (McBain and Trush 2001, p. 8). A 1971 CDFG memo (Coots 1971, as cited in McBain and Trush 2001, p. 35) reported that the 347,288 ft^2 of spawning habitat (from Whiskeytown Dam to [former] Saeltzer Dam) surveyed in 1956 was reduced to only 29,121 ft^2 of habitat in 1971 (91% reduction). In 2000, the same reaches were revisited and 98% of the gravels that were present in 1956 were gone. Previously classified spawning habitat was replaced by stretches of unproductive coarse sand deposits, due to the reduced sediment carrying capacity of the stream and accelerated erosion and sediment delivery by tributaries (i.e., Paige Boulder Creek and South Fork Clear Creek). Sediment supply from Paige Boulder Creek is primarily decomposed granite as coarse sand. “Fine” sediment (<12.8 mm) composition was reported as 30% on average in 1971 (Coots 1971, as cited in McBain and Trush 2001, p. 35). USFWS found that 50% and 48% of spawning gravels were comprised of sediment <13 mm in 1997 and 1998, respectively (McBain and Trush 2001, p. 35), suggesting that the percentage of sediment finer than required for spawning habitat is relatively high and increasing over time.

Salmonid rearing occurs primarily in the alluvial reaches 3 and 4, which is also the location for fall and late fall Chinook salmon (and possible steelhead) spawning (Myers et al. 1998; Healey 1991; Alexander et al. 2003). It is not apparent how much of this historical pattern of rearing was influenced by the migration barrier provided by Saeltzer Dam. Currently, reach 4 provides the highest quality salmonid habitat in lower Clear Creek, and it is heavily utilized by fall Chinook salmon (McBain and Trush 2001, p. 43). However, rearing habitat in these reaches is now simplified due to flow regulation, sediment supply reduction, and gold and aggregate mining (see above) and consists mainly of long pool reaches, in part due to lack of higher flows to mobilize and sort sediment, riparian encroachment, and lack of input of large woody debris (LWD) resulting from channel migration. Floodplain habitats have become largely disconnected from the channel due to a combination of channel and floodplain modifications, and channel incision.

1.6.3 Biotic response

Fish populations

Spring-run Chinook salmon and steelhead populations in lower Clear Creek have been limited by habitat loss, water regulation and high in-stream summer water temperatures (McBain and Trush 2001, p. 8), although increases in baseflow to benefit native fish since 1999 has now reduced the prospect of temperature as a limiting factor. The spring-run population of Chinook salmon in Clear Creek is nearly extinct, and access for both spring-run Chinook salmon and steelhead to spawning and rearing habitat in the upper reaches above (former) Saeltzer Dam had been limited prior to dam removal in 2000 (McBain and Trush 2001, p. 8). Historically, these runs accessed upper mainstem and tributary habitats during the spring high flow runoff, holding over until fall or winter, when spawning would take place (McBain and Trush 2001, p. 8).

Based on USFWS surveys in Clear Creek from 1999–2002, the index of annual adult spring-run abundance (i.e., total number of live Chinook observed during August snorkel surveys) was 9 in 2000, 0 in 2001, and 66 in 2002 (USFWS, unpublished data, “draft report”; info. from Patricia Bratcher, CDFG, pers. comm., 27 April 2004). Based on AD-CWT recoveries during USFWS carcass surveys, it appears that at least some of these fish were hatchery strays from Feather River Hatchery. It also appears likely that there is no clear spatial or temporal separation between spring and fall races of Chinook in Clear Creek (USFWS, unpublished data).

Fall-run Chinook salmon population estimates have fluctuated from 10,000 fish in 1963 to 60 fish in 1978, yet this run is considered to be the most abundant run in Clear Creek (CALFED 1998, as cited in McBain and Trush 2001). In recent years (up to 1999), the estimated fall-run Chinook salmon escapement has frequently been greater than the 7,100 adult escapement target set by the Anadromous Fish Restoration Program (USFWS 1995). Escapement records are not available for late-fall Chinook salmon or steelhead, due to the difficulty in sampling during the winter. Steelhead runs have been described as being small prior to removal of (former) Saeltzer Dam (WSRCD 1996, p. 2-19).

It is likely that native species such as river lamprey, brook lamprey, Sacramento splittail, and riffle sculpin were present in Clear Creek prior to European influence (WSRCD 1996, p. 2-19). WSRCD (1996, p. 2-20) speculated that the loss of low velocity spawning and rearing habitats is the main cause of splittail decline within the upper Sacramento River.

Riparian vegetation

Direct impacts to riparian vegetation in the alluvial reach downstream of Clear Creek Bridge occurred as a result of gravel mining, which often involved the physical removal of large tracts of riparian vegetation growing on floodplains and terraces (TAT 1999, p. 10). Indirect impacts began following the completion of Whiskeytown Dam, as the reduction in the magnitude and duration of high flows caused the virtual cessation of channel migration and avulsion. This caused a reduction in the areal extent of riparian patches of oak, cottonwoods and willow thought to have been associated naturally with abandoned channels and high flow scour channels on the floodplains, and the reduction of organic input to the channel as channel migration virtually ceased. Instead, alterations to hydrology and channel morphology created an environment that selected for plants that seed in the summer (during low water), or for plants that could develop a short-term seed bank (such as white alder) (TAT 1999, p. 10), while the attenuation of winter storm peaks reduced the annual mortality of summer seedlings. This has allowed narrowleaf willow and white alder to encroach along the low flow channel edge where they occupy most of the potential seed beds and fossilize the low flow channel with a simplified age-class diversity and stand structure (McBain and Trush 2001, p. 33-34). Natural riparian regeneration is virtually non-existent, while the remnant floodplain vegetation that predated Whiskeytown Dam is now maturing and becoming senescent (e.g. Fremont cottonwoods >50 yrs old occur in dredger tailing hollows). Wetland emergent vegetation has established within the in-stream and off channel ponds, with narrowleaf willow thickets and bands of white alder surrounding the ponds (TAT 1999, p. 10).

Wildlife

Changes in channel and floodplain morphology and sediment transport processes and subsequent changes in riparian vegetation species composition have altered habitat conditions for a variety of wildlife species in lower Clear Creek. For instance, gravel mining pits provide beneficial habitat for northwestern pond turtles, yet also pose a risk to foothill yellow-legged frogs by providing habitat for predatory bullfrogs. Many bird populations in lower Clear Creek are limited by nesting success, which is correlated with plant species and vegetation structure. Monitoring results from Burnett and Harley (2003) indicate that nest height and substrate choice varied substantially among species, suggesting the need to create diversity in vegetation structure and age of riparian habitat to promote the diversity and reproductive success of the riparian bird community.

1.7 Reference Condition and Post-Disturbance Condition Conceptual Models

To pursue flow-related actions to improve current conditions in lower Clear Creek, it is beneficial to first organize the understanding of historical reference conditions and the more recent pattern of human disturbances to the system into ordered sets of cause-and-effect statements detailing interactions in the contemporary and unimpaired systems. As such, conceptual models of the unimpaired function for confined upper reaches (1 and 2) and alluvial reaches (3 and 4) were developed (Figures 6a and 6b). These are referred to as reference condition conceptual models, and they represent conditions in lower Clear Creek prior to the onset of flow regulation and channel and floodplain mining. Post-disturbance condition conceptual models are presented in Figures 7a through 7d, which represent conditions in lower Clear Creek circa 1996 (following major watershed disturbances, and prior to the onset of restoration actions). Differences between the models are indicative of the impact of human disturbances in altering (usually impairing) ecosystem function. Comparison between the models is the basis for determining the major ecosystem restoration requirements. The arrows in each model imply the direction of causal linkages from the flow and sediment inputs through to biotic response via a series of processes, forms and resultant habitat structures.

1.8 Target Ecosystem Attributes Following Flow Acquisition

Given the reference conditions and historical modifications to Clear Creek, the primary purpose of flow acquisition is to restore those flow and sediment transport processes that are far less frequent under the current flow regime and which are critical to functional ecosystem relationships. Of particular interest is the impact of flow regulation in reducing the frequency of “channel bed maintaining” and “channel morphology maintaining” flows (Stillwater Sciences 2003) characteristic of unimpaired alluvial channels. Acquiring water to promote very large flow events (ten- to twenty-year recurrence) to reset riparian stands to early-successional stages, scour floodplains, and form and maintain side channels and off-channel wetlands is less necessary due to the periodic glory hole spills from Whiskeytown Dam when natural inflows exceed storage capacity. Ideally, flows of an appropriate frequency, magnitude, duration and timing should be acquired to re-establish geomorphic processes that will result in progressive, beneficial, changes to river ecosystem structure and functioning. Although Clear Creek was historically a multi-threaded channel in its alluvial reaches, the continuing effects of Whiskeytown Dam on sediment supply likely make the restoration goal of a multi-threaded channel unattainable. As a result, the following restoration goals represent ecosystem attributes typical of a healthy, single-thread, meandering, alluvial channel, which seems like a more feasible restoration goal in light of the continual need to augment the coarse sediment supply of Clear Creek. Ideally, such a system would include a dynamic pool-riffle morphology, frequent bed mobilization, a balanced sediment budget, channel migration and fairly frequent floodplain inundation (Trush et al. 2000). In the long-term, an increase in the frequency of high flows, channel migration and the input of fallen trees in conjunction with the provision of high flow channels on floodplains may combine to promote channel avulsion and the formation of multi-thread channels to form in some locations.

Goals and objectives

Physical and biological benefits of releasing moderate flood flows are summarized below in terms of three primary project goals. Each goal is broken into a series of objectives that indicate the target ecosystem attributes resulting from achieving the goal. Reach-specific details related to each of these desirable attributes are provided below. The objectives are the precursors to developing a series of hypotheses that test the attainment of objectives and that form the basis for monitoring experiments that will judge the effectiveness of the flow releases. These latter aspects are outlined in Section 2.

Goal #1: Increase the quantity and quality of habitat for salmon.
Objectives include:

a. Increase the recruitment of augmented gravels into the channel, and increase the rates of transport and deposition of both augmented and existing gravel stored in the channel in general and, in particular:
    i. Increase the area and depth of spawning gravels (reaches 1, 3, 4):
    ii. Increase the area of pocket gravel storage in hydraulic backwaters and behind roughness elements (boulder / LWD) (reaches 2, 4);
b. Increase the area of low velocity channel margin habitat for feeding and rearing Chinook and steelhead fry (reaches 1, 3, 4);
c. Increase the frequency and availability of temporary backwater channels to provide rearing habitat and refuge. (reaches 3, 4)
d. Increase instream habitat complexity and cover by recruiting large woody debris to provide juvenile rearing habitat (reaches 1, 3, 4);
e. Reduce interstitial fine sediment accumulation in framework spawning gravels to benefit spawning and juvenile rearing (reaches 1, 3, 4)
f. Increase and maintain pool depth to provide holding habitat for adult spring-run Chinook salmon and steelhead trout (reaches 2, 3, 4)

Goal #2: Promote floodplain development and channel migration processes.
Objectives include:

a. Decrease the volume of fine sediments stored in the channel by routing them downstream and depositing them on floodplains through overbank flooding (reaches 3, 4);
b. Increase the topographic diversity of floodplain surfaces by increasing fine sediment storage on floodplains and the formation of scour channels (reaches 3, 4);
c. Reduce armoring of banks by riparian vegetation and mine tailings using flow scour and supporting management measures (reaches 3, 4);
d. Increase the rate and frequency of outer bend erosion to increase gravel and organic matter (including LWD) recruitment and to increase channel habitat complexity (reaches 3, 4);
e. Increase the in-channel deposition and retention of bed gravel, especially in clay hardpan areas, to reduce thalweg amplitude (reaches 3, 4).
f. Decrease the extent of riffle-runs in straightened reaches riffle using structural roughness elements (logs, boulders) to diversity habitat (reach 4)

Goal #3: Appropriate riparian vegetation recruitment and growth.
Objectives include:

a. Implement flow release schedules that favor the recruitment of desirable vegetation species on floodplains and banks in general (reach 1), but especially to result in:
    i. an increase in the early seral stage component of cottonwood riparian forest (reaches 3, 4);
    ii. improvement in the age and structural diversity of riparian vegetation communities to support bird nesting and foraging (reaches 3, 4)
b. Encourage periodic flow scour of emergent woody riparian vegetation from active channel surfaces (reaches 3, 4);
c. Implement a hydrograph recession limb capable of sustaining capillary fringe height suitable to sustain plant germination and subsequent seedling growth and survival (root contact for x,y,z) on targeted floodplain surfaces.

1.9 Experimental Flow Recommendation

The goal of flow acquisition for Clear Creek is to release discharges of sufficient magnitude, duration and frequency to stimulate the reactivation of geomorphic processes. Such flows were one of a range of possible flow acquisition types discussed for the Sacramento-San Joaquin valleys in general at the Calfed Independent Science Board's Adaptive Management workshop in 2002 (Kimmerer et al. 2002). In total, this group considered *flow increases for attraction or passage*, *elevated base flows* and *flow releases sufficient to reactivate geomorphic processes*. The first two would be considered as "depth maintaining flows" under the high flow classification of Stillwater Sciences (2003) whereas the latter (a "channel bed maintaining" and "channel morphology maintaining" flow) was recommended by the group for Clear Creek:

> "The idea would be to establish a hydrograph that provides either a flow regime close to natural during some seasons, or a "miniaturized natural flow regime", which would provide some of the natural processes but at a reduced flow and in a smaller physical space. This would require continued augmentation of inputs of gravel and possibly woody debris below the dams, since the geomorphic processes would continually move gravel downstream. This manipulation was described as an "acute" effect, lasting a relatively short time, although effects could last much longer." (Kimmerer et al. 2002).

In general, such 'geomorphic' flows were the flow type most highly recommended by the workshop, for their potential of having the greatest impact in a multi-faceted, adaptive management approach. It was also recognized that geomorphic flows present the greatest complexity for planning purposes.

The primary focus of *flow releases sufficient to reactivate geomorphic processes* for Clear Creek is to contribute to the aquatic habitat, geomorphic, and riparian goals outlined in the previous section, and thus complement and support recent restoration efforts in Clear Creek. A key factor for determining the magnitude of a mid-range flood flow is exceeding the minimum threshold required for coarse bed sediment entrainment. In previous experiments on Clear Creek (McBain and Trush 2001, p. 79, 80), the coarse sediment transport threshold was not exceeded at 3,200 cfs, based on sampling at the Igo Gaging Station (RM 10.1, Reach 2). The reasons for this include:

1) Whiskeytown Dam has reduced flood flows and coarse sediment supply, coarsening the channel bed and reducing the frequency of bed mobilization.
2) The channel bed response to reduced coarse sediment supply is winnowing (whereby smaller gravels are transported out of the reach at a greater rate than coarser particles) and a progressive coarsening of the bed surface (Dietrich 1987, as cited in McBain and Trush 2001, p. 80).
3) Loss of coarse sediment supply prevents the stream from being able to adjust its channel geometry to the smaller flow regime.
4) Transport of coarse sediment is hindered in some locations by the combination of a larger channel with less flow and coarser particle size within the bed surface.

Flow Magnitude

As such, the magnitude of the flow releases will need to be in excess of 3200 cfs to allow at least for fine sediment transport, although to scour coarse sediment, flow releases will need to be even greater. Sediment transport on Clear Creek has been examined using sediment transport modeling and field-based monitoring. Sediment transport thresholds were investigated using the Shields equation at 5 sites (Table 3) by McBain and Trush. They placed tracer rocks at 14 cross sections between 1998 and 2000 to verify the sediment transport modeling results (Table 4). In addition

GMA (2003) monitored marked rocks at the floodplain rehabilitation site (Phase 3A) and at Reading Bar. Sediment transport modeling using the Shields equation found that, in general, critical discharge was approximately 3,000-3,500 cfs, although thresholds were much lower in Renshaw Riffle at the upper end of Reach 4 (Table 3). Bedload transport measurements at the Igo gauge site indicated that 3,200 cfs, the highest monitored discharge, was very close to the transport threshold for bedload (medium-sized gravels were in transport, but not the coarser material that makes up the bed). Based on these measurements, McBain and Trush (2001) estimated that the majority of the bed was in motion at this site at about 4,000 cfs. Critical discharge was much less for Renshaw Riffle (RM 5–5.3), likely because of the smaller grain size and narrow channel width at those sites. Bedload transport modeling using the Parker equation at the Peltier Valley Bridge site (in Reach 1) indicate that transport begins at about 3,700 cfs and significant transport (transport greater than about 1 ton/day) begins at about 5,500 cfs. These thresholds would decrease if there is a large gravel infusion in Reach 1.

Table 3. Predicted critical discharge for D84 using Shields equation at various locations in Clear Creek downstream of Whiskeytown Dam (McBain and Trush 2001).

Study Site	Reach	River mile	Predicted Critical Discharge (cfs)
Peltier Valley Bridge	Reach 1	16.2	5,500*
Igo gauging station	Reach 2	10.1	3,400
Reading Bar	Reach 3a	7.6–8.0	3,500
Lower Renshaw Riffle	Reach 4	5.0	1,700
Upper Renshaw Riffle	Reach 4	5.2	1,100
Floodway Rehabilitation Project	Reach 4	2.2–3.8	3,100

*Prediction based on bedload transport rates exceeding 1 ton/day using the Parker equation.

Marked rock studies at Renshaw Riffle (Table 4) found that the majority of the marked rocks moved at about 2,100 cfs, a somewhat higher flow than thresholds predicted by the modeling, but still much lower than for other sites. Bedload and turbidity samples by GMA (2003) GMA (2003) found that models based on Parker's surface bed material equation, which calculates the sediment transport capacity, under-predicted sediment transport rate at Renshaw Riffle for flows greater than about 3,000 cfs and over-predicted measurements for flows less than 3,000 cfs.

These studies show that sediment transport did not occur at Peltier Valley Bridge, which is approximately 1 mile downstream of the dam, and there are no tributary inputs. At this site, discharge did not exceed 250 cfs. This was corroborated by scour cores which showed no sediment transport. Sediment may have been transported at this site during the glory hole spill in 2003, but that spill occurred after the monitoring period had concluded in Reach 1. The floodplain rehabilitation site was mobilized at 3,000–3,200 cfs during 2003 (GMA 2003).

Bed mobility modeling using Shields equation predicted mobility of D_{84} at the floodplain restoration sites at 3,100 cfs. Graham Mathews and Associates found that about 50% of D_{84} particles were mobilized at 3,200 cfs.

Table 4. Tracer Rock experiments conducted by McBain and Trush between 1998 and 2000 (McBain and Trush 2001)

Study Site	Cross Section	Peak Discharge	% D_{50} rock sets moved	% D_{84} rock sets moved
Peltier Valley Bridge	879+00	250 cfs	0%	0%
	883+50	250 cfs	0%	0%
	885+00	250 cfs	0%	0%
	885+00	250 cfs	0%	0%
	886+20	250 cfs	0%	0%
Reading Bar	410+26	2,134 cfs	0%	0%
	411+66	1,926 cfs	28%	7%
	411+66	2,710 cfs	59%	31%
	411+66	2,134 cfs	48%	14%
	426+33	750 cfs	0%	0%
	426+33	2,134 cfs	100%	63%
Renshaw Riffle	273+65	2,134 cfs	78%	40%
	277+55	2,134 cfs	75%	44%
	283+20	2,134 cfs	92%	100%

Recently, GMA (2003 p. 3-13) monitored four winter storm events (December–January 2003) exceeding 3,000 cfs. These included an annual maximum peak discharge of 5,600 cfs, one spring high flow, and a long duration Glory Hole Spill (peak discharge 4,770 cfs). A combination of the high flows and the recent morphological construction of channels in the lower watershed resulted in substantial channel migration and bed mobilization in the restored reach, with more complex habitat as a result (GMA 2003, p. 3-13). In addition, inundation occurred at the 2002 floodplain restoration site, with bank overtopping occurring at 3,000–3,400 cfs. Monitoring has also shown that a relatively high flow is necessary to recruit augmented gravels from floodplain staging sites, particularly the augmented gravels directly below Whiskeytown Dam. In addition to mobilizing a greater size range of particles, a relatively high flow magnitude (>5000 cfs) has been proposed to initiate alluvial processes such as periodic scour of alternate bars, channel migration, and floodplain inundation (McBain and Trush 2001, p. 96), and to offset riparian vegetation encroachment that leads to deeper, simplified habitat (Williams and Kondolf 1999, p. 6). The implication of these experiments is that the required flow magnitude should be in the range 4,000–6,000 cfs to achieve sediment transport.

Flow Duration

Because sediment supply is limited and is achieved largely by periodic gravel augmentation in many reaches, the duration of such flows should be short enough that the total sediment transport does not result in a net loss of storage in each reach. McBain and Trush (2001, p.91) previously recommended a high magnitude, short duration flow event for their "water efficiency" in performing geomorphic work to transport sediment. For example, a 4,000 cfs flow lasting 1 day will move as much sediment as a 2,200 cfs flow lasting 10 days (McBain and Trush 2001, p. 91). Over five times as much water (43,000 compared to 7,900 acre-ft) is projected to be required for the lower magnitude flow release to accomplish the same amount of geomorphic change as the shorter high magnitude flow release, although different sizes of bedload are likely to be moved by the two different flow releases. In such situations, the prospect of enhanced gravel transport out of reaches 1 and 2 (and a potential loss of spawning habitat *quantity*) needs to be balanced against the need to mobilize the gravels to maintain spawning habitat *quality*, and the requirement for coarse sediment transport from the upper reaches to feed the lower reaches, where the geomorphic objectives include raising bed levels to decrease bedrock exposure within the channel

(GMA 2003, p. 1-5). Therefore, continued and possibly accelerated gravel augmentation would be required in the upper reaches.

Flow Timing

If flow timing avoids or significantly minimizes scouring of redds, then the higher flows can be implemented with limited consequences to salmonids. The potential for displacement of newly emerged steelhead fry is unavoidable. However, both Chinook and steelhead fry likely will use the interstitial spaces in the substrate for refuge, assuming that fine sediment infiltration of substrate is not acute. As well, the increased area and access of edge and complex floodplain habitats available to fry for the flow event will serve as refuge and offer a partially compensating effect. As an alternative, high flow could be released in January or February; however, there is potential for scouring steelhead redds in the upper reaches and, to a lesser extent, scouring fall Chinook and late fall Chinook salmon redds throughout both upper and lower reaches. The likelihood of scouring spring Chinook salmon redds is low because the spawning period is from September to October. There may be some potential for a winter high flow event to suddenly provide spawnable habitats for steelhead that are subsequently dewatered, possibly with redds, with passing of the event. However, the duration of flow is sufficiently limited that few spawning steelhead and none of the earlier or later spawners would be affected. Both spring Chinook and steelhead fry from the upper reaches may be displaced. Piscivore spawning behavior is less likely to be disrupted with a winter high flow than with a spring flow. A positive biological consequence of a higher winter flow event would be the greater likelihood of promoting floodplain connectivity and rearing opportunities when compared to a spring high flow event; this is due to the likely higher magnitude flow and tributary accretion during a winter flow release. Planned disturbance events (floods) should be timed to minimize impacts to nesting bird species. The peak of bird breeding activity at Clear Creek (Burnett and Harley 2003) occurs between late April and late June.

Flow Frequency

The frequency of the proposed flow would be relative to the flow magnitude and the statistical probability of obtaining this flow in conjunction with other management constraints on the creek. Obtaining a flow in excess of 5,000cfs once every three years would compare quite favorably with the pre-dam $Q_{1.5}$ of 5,700 cfs.

These flow releases must occur in conjunction with supplementary management actions such as the additional gravel introduction of appropriately sized gravel to maximize their effectiveness and their experimental benefit.

Logistical concerns and the prospects of water acquisition using several scenarios are discussed in Section 2.4.

1.10 Expected Impacts of High Flow Releases

As outlined above, the proposed high flow releases are designed to target several attributes of the contemporary ecosystem of lower Clear Creek which evidence indicates are functioning sub-optimally due to a variety of human disturbances since European settlement (Figure 7). The following narrative describes the expected benefits (1.8.1) and potential concerns and constraints (1.8.2) on such actions ahead of the formulation of specific hypotheses for experimental testing (Section 2).

1.10.1 Potential benefits

Potential benefits to salmon habitat include improved quantity and quality of spawning habitat in all reaches, as well as improved rearing habitat primarily in reaches 1, 3, and 4. These habitat benefits are expected to materialize relatively soon after implementation of each flow release; however, the timing of the biological response to the habitat improvements is uncertain because several factors outside of the Clear Creek basin will influence the population dynamics of several species, especially anadromous salmonids and bird species. Increasing the quantity of available spawning habitat in the upper reaches may be particularly critical for establishing a larger population of spring-run Chinook salmon and steelhead trout in Clear Creek. As noted in Section 1.4.2 (Habitat changes), there has been a 98% reduction in spawning gravels since 1956. Of course, the potential benefit (primarily to spring Chinook salmon and steelhead in the upper reaches) can only be realized when sufficient numbers of spawners return to Clear Creek.

However, it is expected that increasing the quality of spawning gravels, through scouring of in-channel fines, will help increase survival from egg to emergence, potentially increasing the number of fry produced. Delivery of dissolved oxygen to the egg pocket is the major factor affecting survival-to- emergence, which is impacted by the infiltration of fines into the spawning substrate. Several studies have correlated reduced dissolved oxygen levels with mortality, impaired or abnormal development, delayed hatching and emergence, and reduced fry size at emergence in anadromous salmonids (Wickett 1954, Alderdice et al. 1958, Coble 1961, Silver et al. 1963, McNeil 1964, Cooper 1965, Shumway et al. 1964, Koski 1981). Fine sediments in the gravel interstices can also physically impair the fry's ability to emerge through the gravel layer, trapping (or entombing) them within the gravel (Phillips et al. 1975, Hausle and Coble 1976). Therefore, the proposed flows are expected to improve fry production, by improving survival-to-emergence.

Improvement in the quantity and quality of rearing habitat through creation of point bars, off-channel, and low-velocity margin habitat is expected to result from flow releases and gravel augmentation, providing increased rearing opportunity for juveniles. Even with a limited number of spawners, improving the quality of spawning habitat is expected to benefit the production of fry, whilst improving rearing habitat is expected to benefit the production of juveniles through increased survival from the fry to juvenile stages.

Spawning gravel quality is particularly an issue in the upper reaches. Much of the substrate in Reach 1 is currently very angular, due to the lack of high flows necessary to transport and erode the particles into a rounded shape more representative of river gravels and conducive to spawning. As a result, spawning gravel quality is somewhat poor. It is expected that the proposed flow releases will benefit salmon spawning habitat by transporting more rounded augmented gravels into locations on the stream bed amenable as spawning habitat.

In Reach 2, it is expected that high flow events will transport augmented gravels from Reach 1 into Reach 2, where they would be available for deposition behind bedrock and in short stretches of lower channel slope. Although the benefit may not be seen in overwhelming increases in available spawning habitat, it is expected that these pocket spawning gravels may provide valuable spawning habitat for spring Chinook salmon and steelhead. If gravels are added at Peltier Bridge (near downstream end of Reach 1), proposed flows may transport and deposit these gravels into pocket areas available for spawning in Reach 2.

Potential benefits also include somewhat surprising interaction of flow with augmented gravels. For instance, in the lower part of reach 1, a massive slug of augmented gravels was deposited as a mid-channel island as a result of recent high flows, inducing hydraulic complexity in the form of a backwater eddy, riffles, and velocity shear zones (potentially feeding stations for rearing salmon).

Another possible upper reach benefit could be the potential scouring of riparian vegetation and the formation of point bars in Reach 1. Although Reach 1 is bedrock-controlled and not wide enough to allow for channel migration, it is still possible to create some point bar habitat for rearing. Increased habitat complexity may be critical for this reach, as spawning habitat is much reduced compared to historical conditions. There is abundant boulder recruitment in certain areas, where boulders in combination with flow releases may help promote deposition of augmented gravels for available spawning habitat. However, the creation of point bar habitat may likely be an important benefit as well. Typically, riffle-pool complexes are associated with point bars, which would provide greater rearing and spawning opportunities for salmon. Currently, edge habitat is limited, as well as spawning habitat.

Improved spawning habitat in lower reaches is expected to benefit all races of salmon, but particularly fall Chinook salmon. It is more likely that spring Chinook salmon and steelhead will use upper reaches for spawning. Based on surveys from 1999–2002, USFWS found that spring Chinook salmon had a passage rate of 70% above Saeltzer gorge, as compared to only 1.7% for fall Chinook salmon (USFWS, unpublished data). Another long-term benefit then is increased sediment storage capacity, resulting in available gravels for spawning and a continuation of channel migration and floodplain processes which may lead to LWD recruitment and greater potential rearing habitat in the form of alluvial point bars, LWD-formed backwaters, and greater amounts of edge habitat. In addition, expected benefits will include other species such as avian species which can utilize the greater riparian species structure and diversity as well as amphibian species such as yellow-legged frogs, which appear to utilize cobble habitat provided by point bars.

Within lower reaches, particularly in floodplain rehabilitation areas, it is expected that the flow release will continue to help create low velocity channel margin and backwater habitat, as it has in completed phase 2 and 3 rehabilitation areas. Flows have re-worked augmented gravels as the channel has migrated, providing available spawning gravel as compared to the previous channel, which had downcut into the clay hardpan. Assuming that continued gravel augmentation will help maintain coarse sediment storage in the lower reaches, the effects of high flow releases will also benefit salmon rearing habitat by creating more backwater and low velocity channel margin habitat through channel migration.

Floodplain development and channel migration processes are expected to be encouraged within the lower reaches (3, 4). At completed Lower Clear Creek rehabilitation sites, initiation of these processes has resulted in fine sediment deposition on the floodplain and recruitment of willows and cottonwoods. It is expected that a piggyback flow release would help reduce in-channel fine sediment, as most of the fines would be moving in suspension rather than as bedload. The benefit would be improved spawning habitat quality, and increased deposition of sediment onto floodplains, with long-term benefits being improved avian habitat and potentially floodplain rearing habitat for salmonids. The benefit to salmonids would, however, be contingent on a flow regime that allows for frequent and extended floodplain inundation.

It is expected that, as a long-term benefit, upper canopy species such as cottonwood will continue to grow on the floodplain, and that these trees will eventually be recruited as LWD in the future, through channel migration processes. This will require a continued commitment to a flow regime with moderate events (3,000 – 6,000 cfs). In addition, channel migration processes are expected to reduce bank armoring by riparian vegetation and mine tailings. As an example, the phase 3A rehabilitation site has already witnessed unexpected erosion of riparian berms from last year's high flow events. The result has been greater hydraulic complexity, and increased low-velocity edge habitat. As natural recruitment of riparian plants continues to occur over time, there will be greater topographic complexity, further increasing fine sediment deposition and storage on the floodplain. This positive feedback loop will continue to enhance the structural diversity in riparian communities. If timing is factored into the flow release schedule, flows can be used to benefit particular species such as cottonwood by dispersing seeds onto the floodplain in spring.

1.10.2 Potential concerns and constraints

It is possible that summer base flows are relatively high to realize the full benefits of rearing habitat in Reach 1. Historically, flows were much lower, and a reduction in summer base flow may actually improve the amount of available rearing habitat. This could be addressed by expert mapping at a lower experimental flow compared to the normal summer base flow. However, any decrease in base flow must be balanced with spring Chinook holding temperature requirements. The potential gain in rearing habitat could be addressed by expert habitat mapping at a lower experimental flow compared to the normal summer base flow.

Another potential concern involves the input of fine sediment, particularly sand input from Paige-Boulder Creek at the lower end of Reach 1. It may be unrealistic to expect proposed high flow releases to remove this in-channel fine sediment, which reduces our ability to improve the quality of spawning habitat in Reach 1 below Paige Boulder Creek, and Reach 2.. It is also unknown to what extent previous mass wasting events in upstream tributaries may contribute fine sediment to Clear Creek. This question could potentially be answered by an infiltration bag experiment during lower flows (<1,200 cfs) to help better understand fine sediment transport issues.

Reach 2 is dominated by canyon areas, with only a short alluvial stretch. Therefore, the geomorphology of these areas may limit the potential amount of spawning habitat which can be created. Bedrock reaches are typically less productive, but local areas of coarse sediment deposition can have substantial biological importance (McBain and Trush 2001, p. 36). Current conditions can be improved with gravel introductions and increased frequency of moderately high magnitude (4,000–6,000 cfs) flow events. For example, areas behind bedrock features within Reach 2 may provide opportunities for spawning gravel enhancement.

In Reaches 3 and possibly 4, decreased pool depth could be a short-term concern, particularly below Saeltzer Dam gorge. Sediment from Saeltzer Dam in combination with augmented gravels may be filling some of the pools. Pool depth in the Saeltzer gorge area has apparently decreased considerably (Phil Garbutt, WSRCD, pers. comm., 22 April, 2004). In the long-term, this sediment will be routed downstream, and provide a benefit to salmon spawning and rearing. However, the short-term constraint is a reduction in the quality of holding habitat for spring Chinook in lower reaches, natural recruitment of species such as cottonwood and willows relies on a sustained capillary fringe height. A flow recession hydrograph which does not support a suitable capillary fringe height for germination plants will likely prevent recruitment of desirable species such as willows and cottonwoods.

Filling of gravel pits, which is expected to occur with greater floodplain inundation, although beneficial to floodplain habitat, may not be completely beneficial to juvenile fry rearing, as this type of low-velocity habitat has been eliminated. However, this type of habitat is also favorable for piscivores, and has the potential to strand juvenile salmonids. It is unclear what the net outcome from this action is.

For the lower reaches, to keep the channel from downcutting through gravel and back into the clay hardpan, gravel augmentation will need to occur at a rate greater than it is being transported. As rehabilitation efforts in combination with flow releases reduce the slope of the channel, a positive feedback loop will be established where decreased slope decreases the rate of gravel transport. Currently, gravel transport increases greatly at stretches of high slope. With time, the amount of gravel augmentation that needs to occur to maintain coarse gravel storage should however decrease as channel slope is reduced.

Flows, in and of themselves, may not be enough to scour emergent riparian vegetation or existing riparian berms, particularly in Reach 1 where the channel is deep and entrenched. Scouring may not be possible without some form of mechanical alteration. Without reduction in armoring of the banks and periodic scouring of emergent vegetation, it is likely that the existing riparian berms will continue to exist in its current simplified state. In addition, the greater in-channel shear stresses caused by a simplified, steeper channel are likely to transport augmented gravels downstream at a greater rate than if the channel were more hydraulically complex.

As greater magnitude and duration flows are released, the amount of coarse gravel that will need to be introduced will need to be greater, if coarse gravel storage is to be maintained. A potential solution to this is higher magnitude, shorter duration flows.

1.10.3 Requirement for supplementary management actions

Supplementary management actions will be necessary to complement the managed flow releases. It will undoubtedly be necessary to continue and probably to accelerate the program of gravel augmentation to maximize the expected benefits of enhanced rates and distances of gravel transport. It is also unlikely the proposed flows will be sufficient to scour riparian vegetation expect at outer bend locations, and so mechanical vegetation removal should be contemplated with the experimental expectation, that following removal, the high flow releases will assist in reducing the rate of re-colonization. This may also require lower low flows in summer to create drought stress in colonization plants. Other considerations involve structural measures. These could include continued programs of channel and floodplain morphological reconstruction, and the prospect of placing large woody debris in-channel to assist in creating a diversity of hydraulic habitats in locations where there is an absence of such material to be bought into the channel by channel migration. The prospective actions are outlined in Section 3.

1.10.4 Expected post-flow release conceptual model

The post-flow release condition conceptual models (Figure 8) represent expected conditions in lower Clear Creek following the implementation of flow releases described in this proposal and other management and restoration actions such as have already been undertaken such as gravel augmentation, Saeltzer Dam removal and channel and floodplain reconstruction. The differences between post-disturbance condition models and post-flow release condition models are indicative of the effects of managed flows and other restoration actions in altering and improving ecosystem function. It is these expected responses that form the basis for setting experimental hypotheses and effectiveness monitoring programs described in the next section.

2 EXPERIMENTAL APPROACH

Derived from the goals and objectives developed in the last section are a series of hypotheses, organized by project goal and specific to single or multiple reaches, with which we can test our overarching question concerning the ability and extent that managed flow releases can provide benefits to the geomorphology of Clear Creek, and subsequently to its salmon and riparian biomass and biodiversity (Table 5). Testing the effectiveness of the flow releases in achieving the hypothesized benefits is realized through an adaptive management approach. Adaptive management is a systematic, rigorous approach to improving management by implementing policies as planned experiments, monitoring the outcomes of the management interventions, and documenting the results (Taylor et al. 1997). It is not simply changing management policies when they fail to work. Rather, it is a planned approach to reliably learn why management actions or strategies (or critical components of them) succeed or fail using well-planned comparative experiments based on logical monitoring programs. The importance of developing a carefully crafted monitoring program for studying experimental flows has been emphasized by Luna Leopold (1991) with regard to the Glen Canyon Environmental Studies:

> "The use of experimental flows to observe what happens under semi-controlled conditions is one of the scientific methods most likely to add new and useful information to our store of present knowledge. But the full use of these experiments will be greatly compromised if an adequate observation program is not in place at the time that they are operative."

2.1 Monitoring Design Considerations

The proper design of experiments is therefore a critical step in adaptive management programs. In this project, we propose to monitor planned flow experiments focusing on weight-of-evidence hypotheses and on targeted experiments rather than solely to rely on 'status and trends' in the key success criteria (*i.e.*, total salmon population). Such status and trend monitoring will be of benefit to the project but is already being conducted annually by the US Fish and Wildlife Service (USFWS) and thus forms a complementary part to this proposal for adaptation and further development as data become available. A weight-of-evidence analysis refers to a framework for rigorously testing hypotheses in a fashion that helps identify, address and reduce uncertainties in the fundamental issues surrounding the effects of environmental water releases on geomorphic, riparian and fish population responses. Typically through use of structured criteria, the approach aims to determine the overall level of support for key alternative hypotheses from information gained from field research and monitoring programs and to propose other hypotheses that are more consistent with these data.

Table 5. Indicative hypotheses, monitoring methods and performance measures that could be applied to evaluate the effectiveness of flow releases on Clear Creek.

Goal	Objective (see text)	Potential Hypotheses	Performance Measure	Monitoring Methods	Reaches
Salmon habitat quantity & quality	a	Flows will increase frequency & volume of gravel recruitment from bankside input locations	Volume of gravel recruited per unit time	Rate of gravel recruitment	1, 2, 3
	a	Flows will increase rates of transport of augmented gravels	Bedload transport rate, gravel scour depth and/or largest grain size moved	Bedload monitoring, tracer analysis, scour cores/chain	1, 2, 3
	a	Flows will increase the area and depth of available spawning gravel	Area of spawning habitat, gravel depth in spawning areas, evidence of habitat utilization	Expert habitat mapping, gravel area & depth surveys	1, 3, 4
	a	Flows will increase the area of pocket gravel storage	Coarse sediment storage, area of spawning habitat	Expert habitat mapping, gravel area & depth surveys	2, 4
	a	Flows will increase the frequency of sediment transport, improving spawning habitat quality by reducing the average angularity of augmented gravels	Roundness of particles	Measurement of particle roundness following flood events	1
	b	Flows will increase the area of low velocity channel margin habitat	Existence of low velocity, shallow habitat at base flow, evidence of habitat utilization	Channel bed topography / water depth surveys, direct observation	1, 3, 4
	c	Flows will increase the frequency and availability of temporary backwater channels	Existence and area of backwater channels, evidence of habitat utilization	Survey of backwater habitat extent, hydraulic model, direct observation	1, 3, 4
	d	Flows will increase instream habitat complexity	Relative variability of channel bed elevation and channel asymmetry	Channel bed surveys following floods	1, 3, 4
	e	Flows will decrease interstitial fine sediment accumulation in potential spawning habitat	Gravel permeability (and/or grain size distribution)	Permeability tests, bulk sediment texture analysis	1-4
	f	Flows will increase pool depth for holding habitat	Pool depth, area and volume, evidence of habitat utilization	Residual pool depth, direct observation	2, 3, 4
Floodplain	a	Flows will decrease the area of surficial in-	Surface area of channel bed	Facies mapping	3, 4

Goal	Objective (see text)	Potential Hypotheses	Performance Measure	Monitoring Methods	Reaches
development & channel migration		channel fine sediments	with significant component of <2mm material		
	a	Flows will increase the deposition of overbank fine sediments	Surface area of floodplain composed of <2mm material	Sediment trapping	3,4
	b	Flows will increase the topographic diversity of floodplains	Comparative diversity of floodplain elevations in sample locations	Surface mapping survey	3, 4
	c	Flows will reduce armoring of banks by riparian vegetation and mine tailings	Channel width, age of bar and bank vegetation	Bedload/suspended load monitoring, Repeat cross-section surveys, Vegetation mapping and surveys	3, 4
	c	Flows will increase frequency of scour of early-stage riparian vegetation in the active channel	Depth of scour	Scour cores/chains	3, 4
	d	Flows will increase the rate and frequency of outer bank erosion	Channel sinuosity, length of eroded bank	Aerial photographs or thalweg survey, field observations	3, 4
	e	Flows will increase in-channel deposition and retention of bed gravel	Area & depth of coarse sediment storage, reduction of channel slope in sample reaches	Post-flood surveys	3, 4
	f	Flows will decrease the extent of riffle-runs in straightened reaches	Variability of channel bed elevations, pool frequency mapping	Bed survey, habitat mapping	4
	f	Flows will increase deposition of gravels associated with roughness elements	Bed elevation behind roughness elements, substrate size behind roughness elements	Survey, pebble counts	4
Riparian vegetation recruitment & growth	a	Flows will increase the frequency and extent of floodplain inundation	Frequency of flooding and water surface elevation	Monitoring water surface elevations on cross-sections	3, 4
	a	Timing and stage of proposed flows will disperse cottonwood seeds	Number of cottonwood recruits	Vegetation plots	1, 3, 4
	a	Proposed flows will shift the age structure of riparian vegetation towards younger age-	Age of riparian vegetation (long-term)	Long-term monitoring based on vegetation mapping and	1, 3, 4

Goal	Objective (see text)	Potential Hypotheses	Performance Measure	Monitoring Methods	Reaches
		classes		plots	
	b	Instream and floodplain loading of organic matter & large woody debris will increase	Volume and number of LWD pieces	LWD surveys	3, 4
	c	Recession limb hydrograph of proposed flows will be capable of sustaining capillary fringe height suitable to sustain germination	Germination success	Germination plots	3, 4

The requirement for a weight-of-evidence approach arises because the environmental benefits of the proposed flows, especially for biota, are not expected to materialize immediately. For instance, it may take a decade or two for a the geomorphic effects of the flow releases to be fully realized in a channel and floodplain morphology that better benefits fish diversity and so considerably more time will be required to disentangle any effects of these changes on salmon population levels from, for example, the effects of changes in ocean harvest regulations, ENSO and PDO cycles, and so on. Weight-of-evidence approaches therefore provide a structured, "stepwise" way of reducing the uncertainty that these practical considerations bring to the experiment by understanding how each component in the process-form-habitat-biota hierarchy is, in turn, affected by the flow releases. As such, the generics questions for the experiment become:

- Have the changes to hydrology had the expected effects on geomorphic processes? (E.g., are we really moving gravel as often and as far as we wanted?)
- Have the changes to geomorphic processes had the expected effects on stream structure? (E.g., have we really increased gravel recruitment, increased floodplain fine sediment deposition, increased pool depth?)
- Have the changes in stream structure had the expected effects on stream habitat? (E.g., have we really increased spawning habitat quality, the extent of low velocity marginal habitat, etc.?)
- Have the changes to habitat had the expected ecological effects? (E.g., are we really increasing productivity (outmigrants/escapement)?

It is apparent that, further down the bulleted list, the questions become harder to resolve by monitoring, for two reasons. First, the time-horizons become longer, so that it would take longer to determine success even with perfect information. Second, both the accuracy with which things can be measured and the degree to which factors outside project control can be accounted for deteriorate. Therefore, the combination of monitoring under each of the bullets is required to increase the confidence with which the project results can be interpreted. For practicality, the focus of monitoring will be on short-term effects which may be indicative of longer-term trends so that the results are complementary to the on-going status and trends monitoring of fish populations. This will also provide the basis for developing knowledge regarding the effectiveness of the experiment while it is occurring, as a core element in adaptive management.

2.2 Performance Measures and Proposed Monitoring

The goals and objectives developed in Section 1.7 are linked to specific hypotheses, performance measures and monitoring methods in Table 5. The guiding criterion is that, for an experiment to be regarded as "scientific," it should be possible, in principle, to *refute* the hypotheses which are being tested. Monitoring associated with the experiment should consider not only what constitutes evidence of project success, but also what would constitute evidence of failure. For adaptive management purposes, this may include an expert assignment of degrees of belief (subjective probabilities) on alternative hypotheses, taken within a structured decision analysis framework so as to advise institutions on short-term adaptations (e.g. changes to prescribed flow program) that may hold the most promise in maximizing ecological benefits.

In the upper reaches (1 and 2), the primary monitoring goal is to document changes in both the areal distribution of spawning gravels and the quality of spawning gravels in terms of the rate of sediment transport and the depth of scour. The monitoring of geomorphic and riparian vegetation change is essential to assess if the proposed flows and supplementary management actions are accomplishing the physical changes intended, such as mobilizing gravels, and to a more limited extent, restoring alluvial processes in Reach 1, a bedrock-controlled alluvial reach. Fish monitoring will primarily be focused on corroborating habitat utilization of newly created habitats. Without doubt, the ideal measure of project effects and overall benefits throughout the project area would be to monitor changes in the production of early life stages of target salmonid species (Chinook salmon and steelhead). Theoretically, increases in the quality and quantity of incubation, fry, and juvenile habitats should be manifest as increased survival rates to populations of downstream emigrants to the mainstem Sacramento River, and beyond. Practically, however, definitive establishment of such increases is a rigorous, lengthy effort that must account for many factors not directly associated with proposed adaptive management of flows. Incremental improvements directly associated with newly created habitats are, for example, easily masked by inter-annual variability in spawner escapement and fecundity, particularly for the small, remnant Clear Creek population of spring Chinook seen in recent years. On-going fish monitoring by the USFWS and CDFG (downstream migrant trapping, weirs, redd/spawner counts etc.) will be complemented by specific monitoring associated with flow experiments but is not proposed as an explicit, separate task. As fits adaptive management, fish monitoring for life-stage specific survival might be expanded as warranted by results of resource agency monitoring efforts and budget.

The primary monitoring goal for Reaches 3 and 4 is to determine whether or not the proposed flows, in combination with necessary supplemental management actions, have helped improve the quantity and/or quality of rearing habitat available for salmonids. Fish monitoring will be focused on evaluating salmon habitat use and evaluating stranding. Habitat utilization by potential piscivores will also be assessed. Monitoring should also be conducted to monitor the development of alternating bar sequences, floodplain inundation and creation, and establishment of diverse riparian vegetation structure.

In addition, studies for lower flow events (less than 1200 cfs) will also be considered, including an infiltration bag experiment, studying juvenile salmonid response to spring pulse flows less than 1200 cfs, monitoring the abundance, distribution and/or behavior of native resident species, testing of the potential to scour riparian vegetation at the lower flow, and testing the effectiveness of placed large woody debris and boulders in both upper and lower reaches. These studies are not intended to replace studies targeting moderate flow events.

Time frame for monitoring
It is proposed that the monitoring occur for a period of ten years from inception of the project such that such surveys are undertaken ahead of the first managed flow release and are extended through a period of three such releases. This timeframe is based on the idea that the flow releases will occur on approximately a three-year interval. Monitoring should encompass effectiveness monitoring of supplemental management measures that are complementary to the flow releases (e.g., large woody debris recruitment, vegetation management), and should include contingencies to allow monitoring following unplanned flow releases.

2.3 Adaptive Management Prospect

The proposed monitoring program provides the core data for completing an adaptive management in which there is both learning *about* the project in terms of system behavior (i.e., the environmental performance of the high flow releases) and learning *from* the project regarding the adequacy of the assessment process (i.e., the effectiveness of the monitoring program) (Downs and Kondolf 2002). Appraisal requires evaluation in addition to monitoring in order to conclude the experiment and restate the post-experiment conceptual model and also to provide input to the adaptive processes in which knowledge regarding future high flow prescriptions is adjusted and disseminated (Stillwater Sciences 2003). The prospect of further action is then assessed by one of several actions, including re-formulating hypotheses that can clearly be rejected or, where hypotheses were accepted, either by refining the hypotheses based on re-stated conceptual models if significant change was achieved by the experiments or, where the previous experiment did not achieve significant ecosystem changes, a complete revision of ecosystem goals (USFWS and Hoopa Valley Tribe 1999).

In addition, the prospect on Clear Creek of incorporating an existing formal decision analysis model (CCDAM) brings into prospect an explicit and integrated approach to uncertainty reduction that can lead to improved decision-making in the long-term (Von Winterfeldt and Edwards 1986; Peterman and Anderson 1999; Peters and Marmorek 2001). Formal decision analysis is now being applied to many resource management questions and it has been extended to evaluate alternative flow management experiments (Alexander et al. in review). The approach maximizes information value to decision-makers by incorporating and weighting alternative hypotheses and linking hypotheses across sub-systems, often through use of empirical simulation models. The decision analysis approach to evaluating alternative actions with formal accounting of uncertainties is typically summarized using a decision tree (e.g., see example in Figure 9). In the example of Figure 10, new monitoring results provide critically valuable information in the form of revised probabilities for the alternative hypotheses for one or more particular elements of the decision problem. The value of experimentation and monitoring can be assessed *a priori* through simulation using this two-step approach (Alexander et al. in review), where the benefit of an adaptive management experiment is the difference between the outcome of the decision chosen based on the additional sample information (using updated probabilities after each experiment) and the outcome of the decision based on current information (e.g., using prior uniform probabilities on the hypotheses).

In the context of the proposed experiment, and assuming monitoring is initiated prior to the first high flow release, results from the first year of the study should initiate the adaptive management process. For instance, information gained regarding downstream transport of introduced gravels, changes in gravel quality, and changes to channel morphology should help determine the degree of success of that year's flow management/gravel introduction. This information, in combination with further monitoring of the *Lower Clear Creek Floodplain Rehabilitation Project* and continuing status-and-trends surveys of salmon populations, will then be used to better refine flow recommendations for the following season, and also inform recommendations for further gravel introduction and other supplementary management actions.

2.4 Water Acquisition Prospects

Controlled environmental water releases to lower Clear Creek are limited by the size of the Clear Creek outlet, which can yield a maximum discharge of 1200 cfs (Figure 11). Following the completion of Whiskeytown Dam, 82% of the winter and spring floods that do occur are less than 3500 cfs (Figure 12). Downstream tributary inflow and groundwater accretion are capable of increasing the total discharge to reaches 3 and 4, but these flows typically are insufficient to add the additional 1800 to 4800 cfs necessary to achieve discharges between 4,000 and 6,000 cfs (Figure 13). Hence, in the absence of structural modifications to Whiskeytown Dam (see USBR Value Planning Study, 1999), the benefits of moderate 2-day 4,000–6,000 cfs flows (~12,000–24,000 acre-feet by volume) can only be achieved through the use of experimental Glory Hole releases.

The hydrosystem configuration at Clear Creek provides two critical variables in manipulating reservoir storage and the potential for a Glory Hole release. First, 74% of the total annual inflow to Clear Creek since transfer inception has been derived from the trans-basin transfer of water from the Trinity River to Whiskeytown Reservoir through the JF Carr tunnel. This tunnel offers a maximum capacity of 3,600 cfs (Jim DeStaso, personal communication, 2004). Second, 94% of the annual total flow volume exiting Whiskeytown Reservoir (i.e., from both natural inflow and this Trinity water) is passed through the Spring Creek tunnel for power generation purposes. This tunnel offers a maximum capacity of 4,000 cfs (Jim DeStaso, personal communication, 2004). Figure 14 provides the 25th, 50th (median) and 75th percentiles of inflow generated by (a) the Clear Creek watershed and (b) the Trinity River from JF Carr. Figure 15 shows these quartiles for outflows via (a) the Spring Creek tunnel and (b) Clear Creek outlet works and Glory Hole.

Comparison of Figures 14 and 15 reveals that:

- the vast majority of flow diverted to Whiskeytown Reservoir from the Trinity River is passed through the reservoir for power production using Spring Creek tunnel;
- using natural inflows to Clear Creek, the highest probability months for large releases occur in February–April, with precipitous loss in probability after the end of March (Figure 14a);
- the constant outflow totals for spring and summer months relates to the summer base flow management policy (Figure 15b).

The current Whiskeytown Reservoir operating plan is based around a winter water elevation of 1198 feet with the summer elevation increasing to 1210 ft. (full pool) by the end of June. Operation of the reservoir from November 15th through March 31st maintains the water surface as near as possible to elevation 1198 ft.. That operation reduces the probability that high inflows to Whiskeytown Reservoir will result in uncontrolled spills. Beginning in April, Whiskeytown Dam is operated to achieve a reservoir water surface elevation of approximately 1209 feet by May 1st and this level is held constant for the summer recreation season through September. Flood flows in excess of the approximately 37,000 acre feet of storage available from elevation 1198 to 1210 are discharged through the Glory Hole spillway and the Clear Creek outlet works, as well as through Spring Creek Power Plant. Standard Operating Procedures state that in the event of sudden high runoff into the reservoir, JF Carr Power Plant is to be shutdown, the Clear Creek outlet works is to be operated fully open, and discharges through Spring Creek Power Plant are to be increased to the maximum (USBR 1999).

2.4.1 Feasibility of Glory Hole releases through operational changes

Glory Hole discharge is proportional to spillway diameter and water elevation (head) over the spillway crest (Figure 16). The rate at which this water elevation is able to build determines the ramping rate and magnitude of subsequent downstream flows. This flow is a function of the rate of inflow, the hydraulic properties of the Glory Hole spillway, the settings on, and hydraulic properties of, the overall reservoir and its other outlets and sources of natural variation such wind driven Seiche waves and random hydraulic/subatmospheric pressure variability that develops in the Glory Hole throat and tube owing to its physical characteristics. The Whiskeytown Dam Glory Hole has a crest elevation of 1210 feet and reaches its maximum design discharge capacity of 28,000 cfs at a water surface elevation of 1220.5 feet. (Note, the crest of the Whiskeytown Dam itself is 1228 feet).

It is natural to consider the dam safety implications associated with an operational change that would increase the winter/spring reservoir elevation above 1198 feet. On this topic, the engineers participating in the 1999 Value Planning study (USBR 1999) performed for Whiskeytown Reservoir made the following statement:

> "The PMF routing overtops the dam at 53 percent of the PMF, *whether the routing begins with a reservoir pool at elevation 1210 or elevation 1198*. This operation is considered acceptable in terms of a risk analysis which was performed for Whiskeytown Dam. *There would be little change in the safety of Whiskeytown Dam in maintaining the reservoir at elevation 1210 until the desired discharge is accomplished based on flood routing results*." (emphasis added) p.26.

While the added dam safety risk associated with a higher winter/spring reservoir elevation may not be a critical issue, flood risk will to some degree increase due to the decrease in flood storage buffer available with water elevation increases above 1198 feet. Whether this flood risk would prove worrisome would depend on the magnitude of natural inflows and the degree of flood mitigation afforded by routing water down Spring Creek Tunnel and halting trans-basin inflow from JF Carr tunnel.

There are three overall approaches for achieving desired Glory Hole releases. In this proposal, only the first two of those listed below are considered within the scope of EWP's mandate:

1. Leveraging large natural inflow episodes in the late winter and early spring (referred to here as a "piggyback" strategy);
2. Using water from the Trinity River and temporarily halting flows to the Spring Creek Power Plant in late spring or early summer (hereafter just "clear weather" strategy); and
3. Structural modification to the Glory Hole spillway (see USBR 1999).

2.4.2 Leveraging large natural inflow episodes in late winter or early spring

The piggyback strategy is an attempt to achieve desired flows on (a) an incoming/developing storm event or (b) the tail end of a storm event with a clear weather window behind the storm. Operationally, variation "a" might include raising the reservoir from elevation 1198 to elevation 1200–1202 for wet years, 1204–1206 for normal years, and 1207–1209 for dry years sometime in either December, February or March (e.g., depending on medium range inflow forecasts and other factors). Variation "b" might do the same, but most likely the refill timing would occur later in either April or early May.

The requisite inflow and trans-basin supply conditions will not exist in every year to achieve the desired Glory Hole releases, nor would these releases be sought every year. Hence, for in-season implementation purposes, short and near real-time criteria need to be developed to first determine *if* reservoir operations should switch to an '*environmental water release protocol*'. These criteria would need to address operating rules for determining the appropriate reservoir elevation and fill timing as well as the attendant rules needed to govern JF Carr inflows and Spring Creek Power Plant outflows. These in-season criteria would likely include various types of information from:

(a) 1 to 3 month in advance snow-pack/precipitation forecasts for the Trinity, Clear Creek and Shasta basins;

(b) the total allowable flow available for diversion from the Trinity River to Whiskeytown Reservoir (i.e., ROD water year class and flow allowances set by/through collaborations with the Trinity River Restoration Program);

(c) short-run electrical power demand and supply, and foregone power generation costs; and

(d) short-run flood risks in lower Clear Creek and upper Sacramento Rivers.

The piggyback approach has the greatest degree of flexibility in varying the design discharge each year and in being capable of being modified to meet changing hydrologic and socioeconomic conditions. The main costs of this approach owe to foregone power generation lost to (potentially) JF Carr and (primarily) Spring Creek Power Plants. These costs would depend on water year type (i.e., whether surplus water supplies), the volume of water required and the market price of power per megawatt hour. The final cost would need to be negotiated in advance of the shift in protocol and would be redeemed through a payment by the EWP.

In any given year, the likelihood of achieving the desired release is moderate due to weather variation and limitations in inflow forecast capabilities for the system. Also, due to its nature, this approach has a residual degree of loss of control of water releases (USBR 1999), namely for tactical variation "a". However, in extremely large flood years (e.g., 1983, 1998), the Standard Operating Protocol itself does not afford prevailing control over these floods (USBR 1999).

2.4.3 "Clear weather" releases in late spring

The clear weather strategy is an attempt to achieve desired flows in the absence of large storm driven precipitation events to reduce flooding concerns. Operationally, this strategy would involve raising the reservoir operational level from elevation 1198 to elevation 1210 regardless of water year type sometime in late April, May or June. *Since this approach does not have access to meaningful levels of natural inflow, close to 100% of the requisite flow would need to be derived from the trans-basin delivery from the Trinity River by running JF Carr at or near its maximum capacity of 3600 cfs* (Figure 11). To provide for the most rapid building of head over the Glory Hole spillway crest, the Spring Creek tunnel and Power Plant would be temporarily closed, as would the Clear Creek outlet. Thus, a critical unknown is the number of days JF Carr would need to be run at a 3600 cfs capacity (with Spring Creek tunnel closed) to develop the water elevation over the Glory Hole crest that is associated with the target 3000+ cfs discharge.

As with the piggyback strategy, for in-season implementation purposes short and near real-time criteria need to be developed to first determine *if* reservoir operations should switch to this type of environmental water release protocol. Dam operators would likely need to wait until late spring when they can with adequate confidence predict the departure of any (further) worrisome storms. The in-season criteria associated with this strategy would hinge on two main considerations:

1. the total allowable flow available for diversion from the Trinity River (i.e., ROD water year class and flow allowances negotiated with the Trinity River Restoration Program); and
2. short-run electrical power demand and supply, and foregone power generation costs.

Unlike the piggyback approach, under a clear weather strategy the Spring Creek tunnel would for a time need to be completely (or very near completely) shut down, resulting in immediate power generation losses. These costs might be offset somewhat by slightly greater than average power generation at the JF Carr Power House associated with running the tunnel at its maximum capacity.

The clear weather approach offers the greatest degree of flood control protection but limits the magnitude and possibly duration of environmental releases if foregone power generation costs turn out to be significantly higher than those associated with piggybacking. Also, the total volume of water required will depend on the amount of time it takes to build the requisite water elevation over the Glory Hole crest to achieve the 3000 to 3600 cfs release magnitude.

Table 6 summarizes the overall trade-offs and major uncertainties associated with the piggyback and clear weather approaches.

Table 6: Qualitative summary of trade-offs and key uncertainties/considerations associated with piggyback and clear weather alternatives for generating environmental water releases in Clear Creek.

Environmental water release alternative	Approximate range of water required or available (acre-feet)	Expected return interval (probability of achievement)	Lower Clear Creek flood potential	Trinity River water diversion requirements	Foregone power generation (Spring Creek PP)
Piggybacking (December to April)	15,000 to 41,000	Perhaps better than 1 in 5 years – *not known?*	Higher	Lower	Lower
Key variables/ uncertainties	Magnitude and timing of storm inflow	Weather and operational tactic dependent	Downstream tributary inflows	ROD, TRRP, Water Year	Cost formula, value of power
Clear weather approach leveraging Trinity River flows (May to June)	15,000 to 21,000	More control, more frequent	Lower	Higher	(Likely) Higher
Key variables/ uncertainties	Time required to build necessary head over Glory Hole crest	Operational tactics	n/a	ROD, TRRP, Water Year	Cost formula, value of power

3 REGIONAL CONTEXT

3.1 Previous Restoration Projects

Beginning in 1996, a suite of restoration programs have been implemented in lower Clear Creek. These include gravel augmentation periodically since 1996 to replenish spawning gravels lost following the disconnection of the upper and lower watershed, increases in baseflow to benefit native fish since 1999 (to 150 cfs in spring and summer and 250 cfs in fall and winter from 5 and 20 cfs, respectively, set initially after the onset of Whiskeytown Dam operations), morphological reconstruction of 2.2 miles of channel and floodplain morphology as part of the *Lower Clear Creek Floodway Rehabilitation Project* (2000–present), removal of the 15 ft-high (former) Saeltzer Diversion Dam to provide access to an additional 10 miles of habitat in the lower watershed, and best practice management measures to reduce upslope fine sediment supply from tributaries using. Additional information on these restoration measures is available in the following sources: Aceituno (1985), Burnett and Harley (2003), California Department of Water Resources (1986), GMA (2003), McBain and Trush (2001), Miller and Vizcaino (2004), and USBLM (1999).

Environmental conditions in lower Clear Creek are already improving as a result of restoration efforts (and recently increased base flows), but still require increased frequency of moderate flows. Provision of managed flow releases will build upon efforts to date and sustain ecosystem processes which create desirable habitat conditions for salmon and other species.

3.2 System-wide Ecosystem Benefits

In addition the anticipated direct benefits of the high flow releases to target geomorphic, salmonid, and riparian objectives, there is the potential to indirectly benefit several other aspects of the Clear Creek ecosystem, namely:

- **Native frog populations:** The tadpoles of introduced bullfrogs must overwinter, and cannot tolerate high-flow events during this period; consequently, the proposed flows are likely to suppress the spread of bullfrogs in the Clear Creek basin. Introduced bullfrogs are regarded as an important factor in the decline of the California red-legged frog, and it is suspected that they prey on foothill yellow-legged frogs where they co-occur. Foothill yellow-legged frogs are strongly associated with the stream features that the proposed flows are intended to create: breeding occurs in shallow, flowing water, with at least some gravel and cobble substrate; adults appear to prefer gravel/cobble river bars along riffles and pools with at least some shading.

- **Native bird species:** Enhancing backwater marsh habitat in old river channels (as was created as part of the Phase 3A Restoration) using high flow releases will increase the amount of creek side habitat favored by many species at Clear Creek, including Yellow Warbler and Song Sparrow (Burnett and Harley 2003, p. 31). Song Sparrows have colonized the mouth of scour channels where natural recruitment of herbaceous cover has occurred (Burnett and Harley 2003, p. 31). Many of the riparian focal species at lower Clear Creek, such as Spotted Towhee, Song Sparrow, and Yellow-breasted Chat, nest in low-lying vegetation. Understory species such as mugwort are positively correlated with nest success in several riparian songbird focal species. More diverse and structurally complex floodplain and riparian vegetation is anticipated to promote a more diverse bird community.

- **Resident trout populations:** Resident trout should also benefit from the prescribed flows and gravel enhancement. The substrate composition selected by rainbow trout for spawning tend to be slightly smaller in size than for spring Chinook salmon; however, particle size of selected spawning gravels are influenced by factors other than fish size (e.g., water depth and velocity, cover, upwelling or downwelling currents) (Kondolf and Wolman 1993, p. 2283, 2284). If variable size fractions are used in the introduced gravel mixtures, then resident fish will be more likely to benefit. One resident rainbow trout has been observed spawning in previously introduced gravels deposited in a pool tail (McBain and Trush 2001, p. 12).

- **Reduction in exotic plant species:** The expectation that flow releases will cause changes in channel and floodplain habitat structure somewhat towards pre-disturbance conditions provides the indirect prospect that many of the non-native plant species that have thrived under disturbed conditions may be less well suited to the "improved" conditions or, at least, they will be less able to complete with native species in the altered areas.

There is also potential, under the EWP program in general, to develop useful comparisons with other EWP projects, as they are implemented, thus contributing to the stock of potentially transferable information of use to Central Valley and other river systems. Two prospects here include a direct comparison between the results of various experiments where there are overlaps in the project objectives and, second, the prospect of including deliberate contrasts in later experiments to contrast with the approach taken for Clear Creek. Clearly, this information is a longer-term program goal and will need dedicated resources.

3.3 Resource Implications and Limiting Factors Not Addressed

Passage barriers and high water temperatures affect many fish populations in the Central Valley but are deemed to be of less impact in Clear Creek, and were thus not addressed in the identification of desirable ecosystem attributes by reach (section1.6). The removal of Saeltzer Dam is thought to have removed the primary impediment to access to upstream spawning sediments, based on flow experiments conducted in 2002 (Alexander et al. 2003, p. 84). It is possible that, during drought years, the wide, steep gradient reach of Clear Creek above the confluence with the Sacramento River may limit upstream passage of adult fall Chinook. Natural passage barriers through several of the bedrock canyon sections may still provide some natural migration barriers under low flow conditions. Fish barrier studies conducted by USFWS indicated that a partial barrier (defined as a barrier to some salmon at all flows) exists at river mile 6.5, the Saeltzer gorge (USFWS, unpublished data; pers. comm., Patricia Bratcher, CDFG). USFWS estimated a passage rate of only 1.7% for fall Chinook based on carcass recoveries downstream and upstream of the gorge, and 70% for spring Chinook salmon based on snorkel surveys (USFWS, unpublished data; pers. comm., Patricia Bratcher, CDFG). The provision of enhanced baseflows in summer months is likely to reduce flow temperatures in critical periods, thereby reducing the effects of elevated temperature on salmonids. Also, it is believed from stakeholder accounts, however, that some combination of higher baseflows and lower temperatures have reduced the distribution and population(s) of non-native fishes, including potential salmonid predators that could limit production. A separate investigation of salmonid predation is not proposed at this time.

3.4 Key Learning Opportunities

Scientific assessment of managed high flow releases is in its infancy. Assessment is probably best documented for the 1996 Grand Canyon Controlled Flood (i.e., Webb et al., 1999) but the flow release objectives and morphodynamic type of river involved (*i.e.*, sand-bedded in a bedrock canyon) are somewhat dissimilar to the Clear Creek case. Essentially, the proposed approach is one of partially restoring the 'flood pulse advantage' to channel ecosystems. The required high flows should be defined based on the management objectives for the system, as outlined above. However, as the operation represents only a partial return of the pre-regulation hydrograph (and inherently deals only with sediment transport, not sediment supply), various conflicts can arise between management objectives, including:

- Gravel mobility vs. gravel loss
- Scouring marginal vegetation vs. gravel loss
- Floodplain building vs. in-channel diversity
- High flows vs. hazards and water resources management (Kondolf and Wilcock 1996)

Partly, these concerns can be offset by supporting management actions but it should be recalled both that (1) setting experimental discharges is an exercise in creating an inventive flow regime that interacts with a highly modified sediment budget to attempt to produce a sustainable and ecologically acceptable river channel, but one that has few naturally-formed counterparts, and (2) there are currently insufficient examples of carefully planned and targeted high flow releases to categorically prove their claimed utility (Downs and Gregory 2004). As such, the uncertainties surrounding such management actions are high and require a strategically applied and carefully monitored approach to ensure the greatest possible project benefit. Approaches will differ according to the ecosystem objectives of the project and the type of high flow applied (see Stillwater Sciences 2003). Conversely, the prospect of a well-monitored and evaluated approach providing numerous learning opportunities is also high. Monitoring will require an approach focused on weight-of-evidence hypotheses and on targeted experiments rather than simply on 'status and trends' in the key success criteria (*i.e.*, total salmon population), as detailed in Section 2.

Uncertainties and Learning Opportunities by Reach

Reaches 1 and 2

- **There is limited information on tributary flows** and their relationship to rainfall patterns, which should be improved with future stream gaging efforts. Greater knowledge of tributary flows should improve understanding of the potential effect of accretion on mobilization of augmented gravel and cleaning of subsurface fines in Reach 1.
- **The extent of subsurface fines is currently unknown**, but an infiltration bag experiment can help assess the extent of fine sediment infiltration during natural storm events. Models such as CCDAM have assumed that fine sediment contribution from tributaries is flushed out of the system (Alexander et al. 2003, p. 50).
- **The volume of tributary gravel input is unknown**. Studies should target monitoring both fine sediment and gravel input from tributaries.
- **Input from mass wasting events is poorly understood**. Studies investigating sediment sources and input mechanism would be beneficial in the long-term understanding of the creek.

- **It is uncertain whether spawning habitat is actually limiting** spring Chinook and steelhead production, although it is likely to be a factor given that so much spawning habitat has been eliminated since the construction of Whiskeytown Dam. Currently there is no clear evidence supporting or disputing that spawning habitat is limiting. It was estimated that current spawning habitat may support spawning for approximately 88 pairs of Chinook salmon based on the estimated area of spawning habitat and habitat area requirements (McBain and Trush 2001b, p. 9).
- **There is uncertainty related to partial sediment transport.** It is yet to be proven empirically whether it is feasible to remove fine sediment from the channel bed without significant mobilization of coarse sediments.
- **Investigate opportunities to experiment with gravel augmentation size ranges.** Introducing different size compositions of gravels in augmentation projects will help define a relationship between flow and annual sediment transport rates, to further refine the choice of substrate composition of future gravel introductions. Varying the size composition may also provide spawning habitat for more species to utilize.

Reaches 3 and 4

- **It is probable that moderate flood flows cannot remove significant amounts of encroaching vegetation**. An adaptive management approach will be needed to develop a high flow schedule to improve rearing habitat conditions by decreasing conditions suitable for vegetative encroachment. It is possible that the low flow schedule will also need adjusting to create drought stress in the encroached vegetation. Further, it is unlikely that the moderate flood flows will be capable of removing vegetation by scour except, perhaps, at the outside of meander bends. Therefore, mechanical removal may be necessary.
- **The no conclusive understanding of the role of large woody debris in Clear Creek.** Williams and Kondolf (1999, p. 5, 6) speculated that logging which accompanied early mining efforts may have depleted the sources of large wood available for recruitment. The uncertainty is whether with improved riparian conditions and routine and episodic recruitment of LWD to the channel will increase in-channel loading sufficiently to act a geomorphic agent. The role of LWD in fluvial processes of island formation, channel avulsion, etc. is widely understood, as is utilization of LWD associated habitats by all life stages of salmon. What is not known is the extent that LWD-associated features were present in lower Clear Creek., owing to historic, extensive modification of floodplains.
- **If pool habitats are improved for holding adults, what are the trade-offs for rearing and emigrating fry and juvenile salmonids?** It has been assumed that current shallow pool habitat is not satisfactory in terms of depth, velocity and complexity (Biologist subteam meeting notes, February 20, 2004) as holding habitat for adults, These same habitats may know be utilized by fry and juvenile salmon at various time of the year. The opportunity and uncertainty is to identify a proportion of various habitats that benefit all life stages.
- **Use of the current habitat by non-native predators is poorly understood** at this point. Introduced non-native predators may also be affected by actions intended to improve rearing habitat for juvenile salmonids. Restoring more natural alluvial conditions may decrease habitat for predators, since native species are adapted to the dynamic conditions of an alluvial river system.
- **Is rearing habitat limiting survival**?: one of the most substantial uncertainties is whether rearing habitat is limiting survival in Clear Creek, particularly since rearing in the cooler mainstem Sacramento River may be occurring. It is thought unlikely, but is

possible that water temperatures may not be cold enough in Clear Creek to support summer rearing, and therefore improving rearing habitat may not result in increased rearing success for juvenile salmonids.

- **Uncertainties related to bird population relationships to habitat.** Monitoring results (Burnett and Harley 2003, p. 30) illustrate that it is not sufficient to solely monitor the abundance and diversity of bird populations in order to determine if a site is providing high quality breeding habitat. Habitat sinks (sites where birds do not have sufficient reproductive output to sustain the population, so populations only persist due to an influx of birds from more productive sites) may have the same abundance or density of birds as more productive sites. Monitoring both bird abundance and distribution, productivity, and survival are all critical components of determining the quality, or value of habitat to a bird community (Burnett and Harley 2003, p. 30).

4 COST

Cost estimates for the proposed project are dependent on the price of foregone power and extent and type of monitoring proposed as part of the project. A cost estimate will be produced once feedback has been received on the proposed monitoring approaches.

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